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JSC Mars-1 Martian Regolith Simulant Particle Charging Experiments in a Low Pressure Environment

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Abstract

NASA has a keen interest in Martian dust particle charging as it impacts future Mars missions. The particle charging can be used in experiments to help gather information about atmospheric electrostatics, saltation, and tribo-electric charging. Additionally, the charging could also be a nuisance for equipment because of the potential hazard of electrostatic adhesion and discharge.

In order to gather more information about the nature of particle charging at Martian atmospheric pressures, experiments were performed in a 7 Torr environment testing the contact and frictional charging of the JSC Mars-1 Martian Regolith Simulant. An apparatus was devised that dropped the simulant down a deflection board whose surfaces were coated with various materials of interest. The particles were illuminated by a UV source as they fell. The UV illumination was added to consider whether the surface states of the particles would be augmented to permit greater tribo-charging. The charged particles would then exit the board into a Faraday cup to measure the amount of charge accumulated using an electrometer. The materials used on the deflection board surfaces included copper, glass and acetate.

The degree of particle charging measured for each surface proved to be consistent with the tribo-series table. The UV source did not significantly altered the experimental outcomes.

1. Introduction

NASA has expressed concern about electrostatic charging on Mars. It is well known that the Martian atmosphere is dry and windy and that conditions should be very conducive to particle charging. The particle charging can be used in experiments to help gather information about atmospheric electrostatics, saltation, and tribo-electric charging. The charging could also prove to be a nuisance for equipment because of the potential hazard of electrostatic adhesion and discharge. Consequently it is necessary to test under which conditions and with which materials will tribo-electric charging become significant.

Cameras on board the Viking Lander and on Pathfinder revealed considerable amounts of dust in the Martian atmosphere. Greeley, Lancaster, Lee and Thomas [1] as well as Sentman [2] discuss the potential threat of electrostatic discharge due to saltation on Mars. Saltation is the process where particles are lifted into the wind stream, are carried for a distance, fall back to the surface, and possibly kick up more particles repeating the process. The saltation action can create highly charged particles leading to adhesion and discharge. Since wind gusts in the Martian atmosphere can reach velocities of up to 100 meters/second, saltation and impact charging can be a significant issue in electrostatics on Mars.

In order for tribo-charging to take place, a dynamic contact between two surfaces must occur. The main types of dynamic charging are sliding, rolling, vibration, impact, rupture, separation, deformation, or charging at a cleavage of crystals. All of these mechanisms can take place during the saltation process. Matsuyama, and Yamamoto [3,4] discuss particle impact charging on metal plates as a function of velocity. It appears that the accumulated charge is directly proportional to pressure at contact. Harper explains this by the Volta-Helmholtz hypothesis [5]. It has also been speculated that charging of dust can occur simply from UV radiation (Watson [6], Rosenberg, Mendis and Sheehan [7], Horanyi, Robertson, and Walch [8]).

In light of the fact that saltation is significant on the Martian surface and that tribo-electric charging is inevitable in that environment, we developed an experimental apparatus to test charging due to sliding, rolling and impacts on various surfaces in a 7 Torr environment.

We also included UV radiation to test whether or not it would augment the surface states and thereby enable greater tribo-charging.

2. JSC Mars-1 Martian Regolith Simulant

The Kennedy Space Center provided the simulant, which was formulated by the efforts of Allen, Jager, Morris, Lindstrom, Lindstrom, and Lockwood [9,10]. The chemical composition of the simulant is shown in table 1 below.

Table 1.
Chemical Composition of JSC Mars-1 Simulant

OXIDE	WT%
SiO_2	43.5
Al_2O_3	23.3
TiO_2	3.8
Fe_2O_3	15.6
MnO	.3
CaO	6.2
MgO	3.4
K_2O	.6
Na_2O	2.4
P_2O_5	.9

The grain size distribution by wt% is given in Table 2 below.

Table 2.
JSC Mars-1 Grain Size Distribution

SIZE(μm)	WT%
1000-450	21
449-250	30
249-150	24
149-53	19
52-5	5
< 5	1

It should be noted that, with the vast range of grain sizes as well as the diverse chemical composition, it will be difficult to predict which constituents or which grain sizes contribute most to the tribo-charging process. Bi-polar charging can occur where the different simulant constituents charge differently. Therefore, the Faraday cup will only measure the aggregate charge after the sample is tested. The smaller particles will tend to cling to the testing surfaces whereas the larger particles will continue to fall through the deflection board and into the Faraday cup. Therefore, in each trial, the total net charge falling into the Faraday cup will be minus the charge accumulated by the particles that fail to fall into the cup for various reasons. Some interesting work has been done demonstrating that the smallest particles tend to charge negatively while the larger ones charge positively (Diaz, Wollman, Dreblow [11]).

3. Experimental Apparatus

An apparatus was built to test tribo-charging of the JSC Mars-1 regolith against various materials. All experiments were conducted in a 7 Torr vacuum with air. The action of bouncing, rolling, and sliding was accomplished by dropping the simulant down a deflection board. The surfaces of the board were covered with copper, acetate, or glass sheets. Additionally the particles were exposed to UV radiation. We speculated that the rolling, sliding, and bouncing of the simulant particles would result in a net charge transfer, which could be measured with a Faraday cup and electrometer. Obviously, the particle speeds will not compare to the higher velocity dust storms on Mars. We did not try to simulate the Martian atmosphere by testing in a predominant CO_2 environment. While the room temperature remained relatively constant at 22^0 C, we did not regulate nor measure the relative humidity. Therefore, this experiment cannot predict accurately charging conditions in the Martian environment. However, the experiment can serve as an indicator of the effects of tribo-charging between the Martian simulant and various surface materials under the conditions stated.

The schematic representation of our experiment is shown in figure 1 below. The details of the experiments and the outcomes can be found in the final NASA report by Gross and Grek [12].

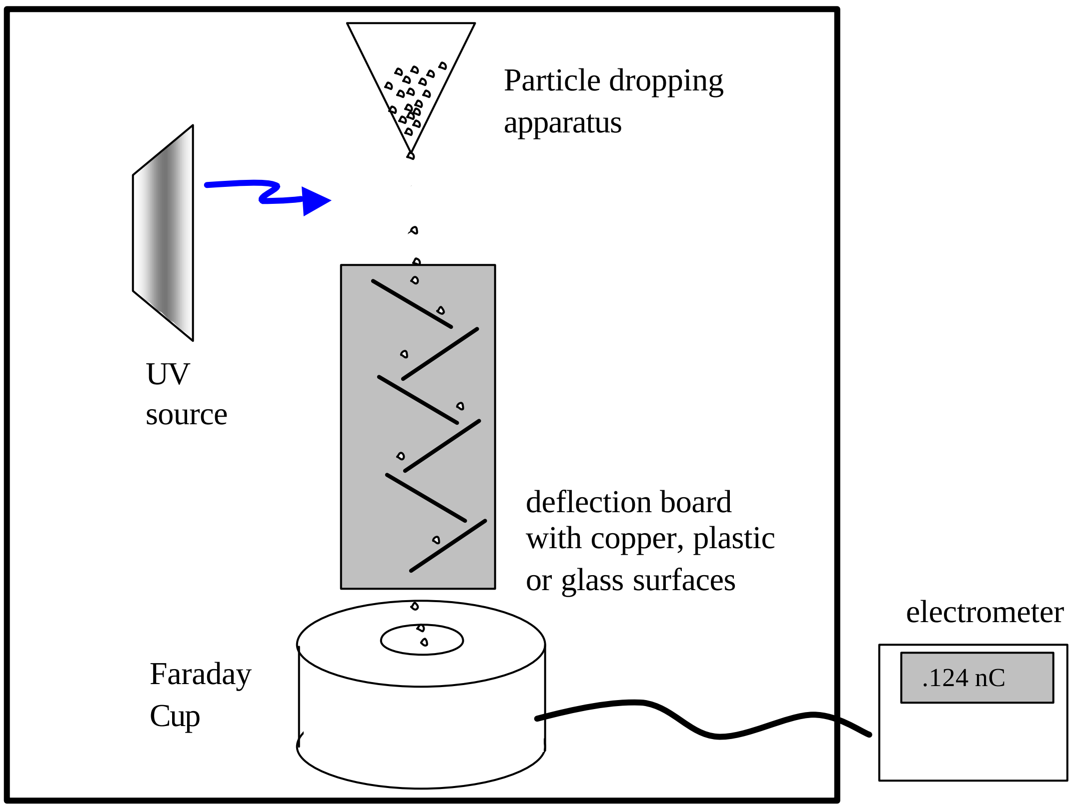

Figure 1. Diagram demonstrating the particles falling in our apparatus

In order to test the charging characteristics of JSC Mars –1 simulant under low pressures, we devised an apparatus composed of the following items: 1). Bell jar, 2). Vacuum pump, 3). Vacuum gauge, 4). Remotely controlled particle dropper, 5). Deflection board with coated surfaces, 6). Faraday Cup and electrometer, 7). UV source, 8). Scale, 9). And a discharge cup for holding and neutralizing the samples.

Particle deflection board

Our particle deflection board is made of oak and has removable slides that can be fixed to the surface at any angle. We found that an angle of 45^0 was the best compromise between maximizing particle velocities and maximizing the time of exposure to the surfaces. Smaller angles allowed too much of the simulant to adhere to the deflection surfaces. Figure 2 below shows the deflection board as well as the points of entry and exit. The particles slide down each miniature slide and fall off onto the next slide. The falling-rolling-impacting motion helps to produce a charge transfer from the simulant to the surfaces or vice-verse.

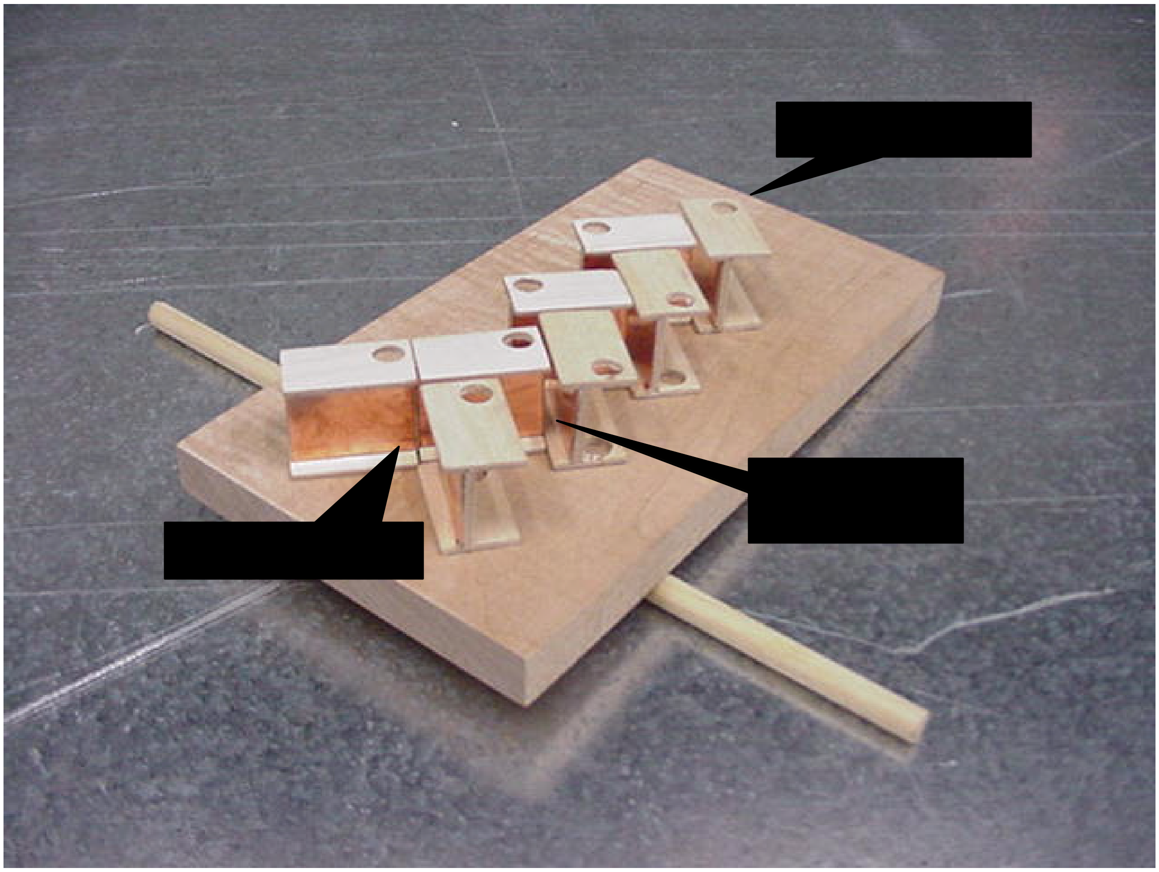

Figure 2. Deflection board coated with copper plates. Particles enter at point 1 and exit at point 2 into the Faraday cup.

Three possible materials are placed on the deflection board shown in figure 2: 1) copper, 2) acetate, and 3) glass.

Remotely controlled particle dropper

For each trial, 1 gram of the JSC-1 simulant was weighed. The sample was placed in a grounded copper cup to be transported to the vertical holding tube at the inside top of the bell jar. The stopper was put in place to hold the simulant. The deflection board, for testing the particle charging, is placed above the Faraday cup. The system is evacuated to approximately 7 Torr. Finally the stopper is removed via remote control and the particles fall down the deflection board. The particles partially slide and partially bounce making several collisions with the material being evaluated. After the last particles have fallen into the Faraday cup, the electrometer is used to measure the net charge within the cup. Obviously there are more charging mechanisms in play than just contact with the deflection board. The simulant holder will induce some net charge, the smallest grains may drift out of the aggregate as the particles are falling, and tribo-charging will occur within the simulant while each grain is moving against its neighboring grains.

Additionally we made measurements of charging when no deflection board was present and the particles simply fell into the Faraday cup.

UV radiation device

The ultra-violet source was a Spectroline PE 140T UV light. The lamp has a paraboloidal reflector behind the bulb and therefore radiates all of the energy towards the dropping simulant particles. The wavelength of this unit is 254 nanometers. The "irradiance rating" or typical peak intensity of this unit is 8000 $\mu W/cm^2$ at that wavelength.

Typical UV radiation intensities on the earth's surface are 25$\mu W/cm^2$. There is some indication that UV intensities on Mars are comparable [13]. Therefore, our UV radiation intensity is considerably higher than would be encountered in the actual Martian environment. Each material is tested with and without UV. Therefore, there were a total of eight trials conducted.

4. Experimental Results

We performed four sets of experiments:

1). Straight drop of the simulant into the Faraday cup,

2). Drop the simulant down deflection board with copper surfaces into cup, 3). Drop the simulant down the deflection board with acetate surfaces into cup,

4). Drop the simulant down the deflection board with glass surfaces into cup.

In all cases, we tested the charging of the simulant with and without UV. A description of all eight trials is detailed in table 3 below.

Table 3
The different trials testing the JSC Mars-1 Martian Regolith Simulant

Trial no.	Description
1	Straight drop of simulant into the cup with no other influences.
2	Straight drop with UV applied
3	Through deflection board with copper face plates
4	Through deflection board with copper face plates with UV
5	Through deflection board with acetate face plates
6	Through deflection board with acetate face plates with UV
7	Through deflection board with glass face plates
8	Through deflection board with glass face plates with UV

In all trials, we first measured a sample of the simulant with a goal of dropping exactly one gram. After every trial, we normalized the charge measured by the actual weight dropped to achieve a charge per gram measurement. For example, if we dropped 1.03 grams of simulant to measure .24 nC of charge, we normalized the charge by 1.03 to get .233 nC/gram.

In the case of the straight drop with no deflection board, the particles fell a distance of 29 cm into the cup. The falling particle velocities are much lower when the deflection board is in place. Each trial was performed ten times to check variations from trial to trial and to find an average charge for that trial.

Trials 1-2 Straight-drop into Faraday cup

Figure 3 shows the measurements for the straight-drop case with and without UV.

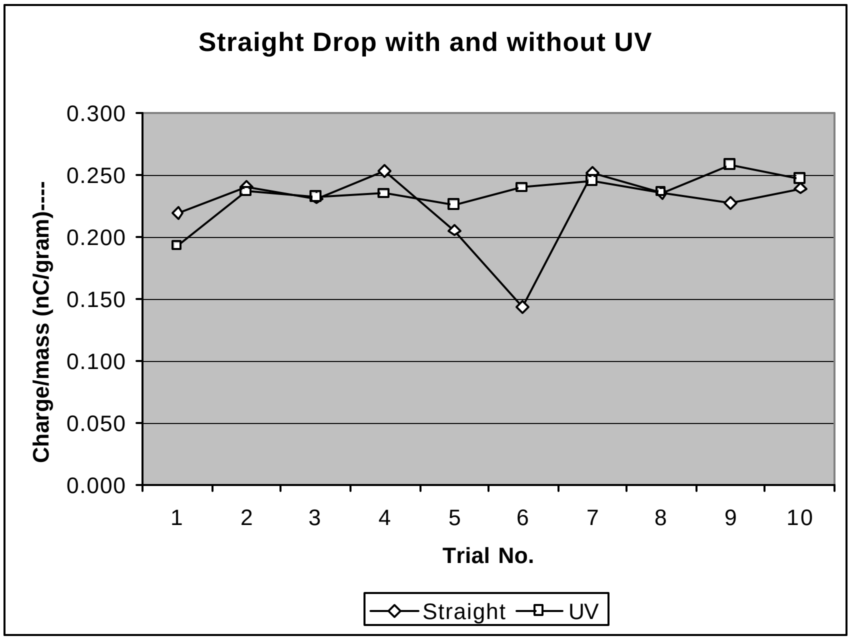

Figure 3. Simulant Charge with straight drop with and without UV

The straight drop trials showed a net positive average charge of .225 nC/gram. It appears that the UV radiation did not affect the charging of the Martian simulant even though dust charging for a lunar simulant has been reported [8]. We speculate that the simulant transferred additional charge to the bottom of the cup due to impact and bouncing.

Trials 3-4 Copper deflection board

Figure 4 below shows the measurements for the copper deflection board with and without UV. The copper was copper tape placed on the sliding surfaces with spray glue for easy removal.

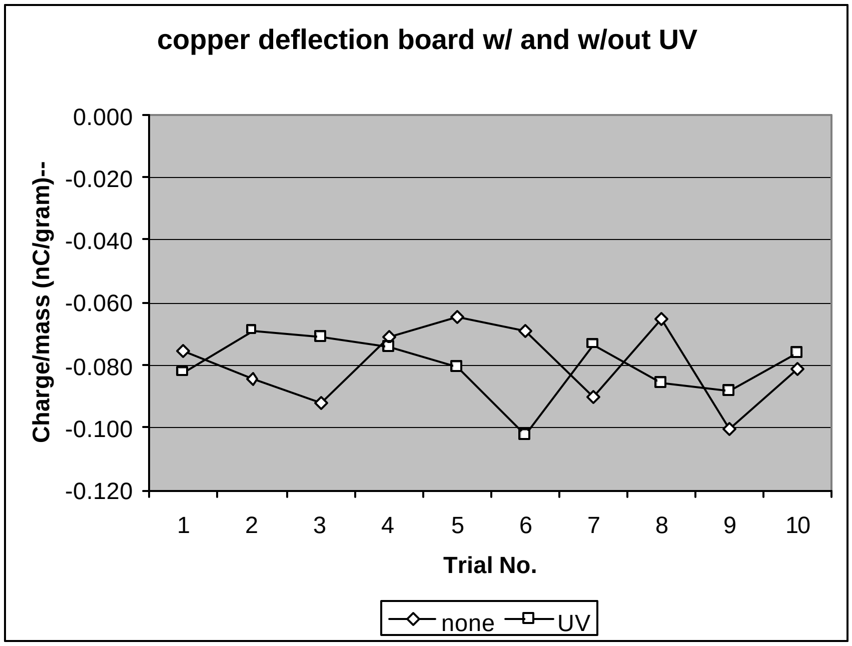

Figure 4. Simulant charge with copper deflection board with and without UV

The copper deflection trials showed that a net negative average charge of -.08 nC/gram accumulated in the Faraday cup. It appears again that UV does not affect the charging of the particles. Copper yielded the smallest tribo-charging values.

Trials 5-6 Acetate deflection board

Figure 5 below shows the table of measurements for the acetate deflection board with and without UV. The acetate was cut out from overhead transparencies and attached to the deflection board with spray glue.

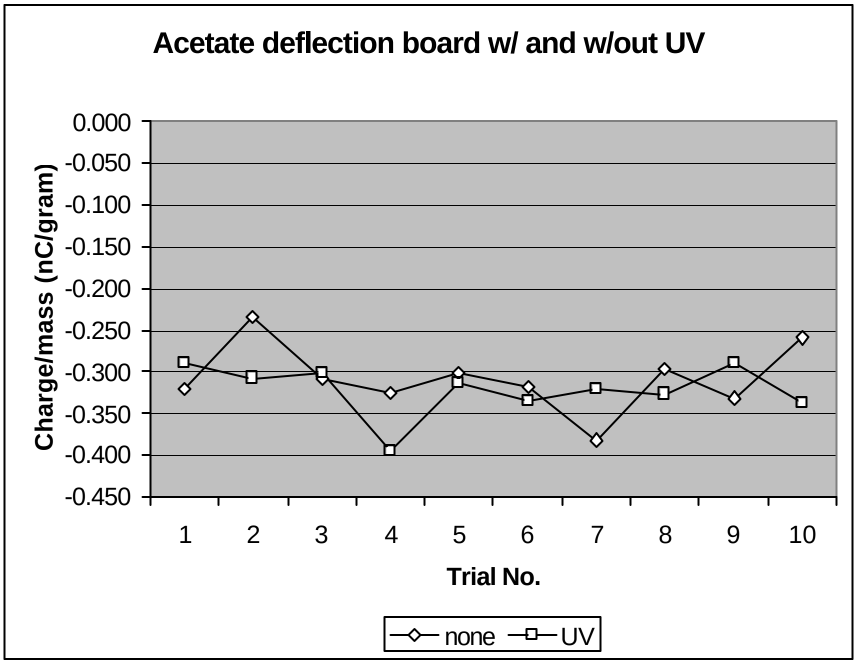

Figure 5 Simulant charge with acetate deflection board with and without UV

The acetate deflection trials showed that a net negative average charge of -.308 nC/gram accumulated in the Faraday cup. It appears again that UV does not affect the charging of the particles. Acetate yielded the largest magnitude tribo-charging.

Trials 7-8 Glass deflection board

Figure 6 below shows the measurements for the glass deflection board with and without UV. The glass is a common soda-lime glass which contains 60-75% silica, 12-18% soda, 5-12% lime. The glass is also attached to the board by spray glue for easy removal.

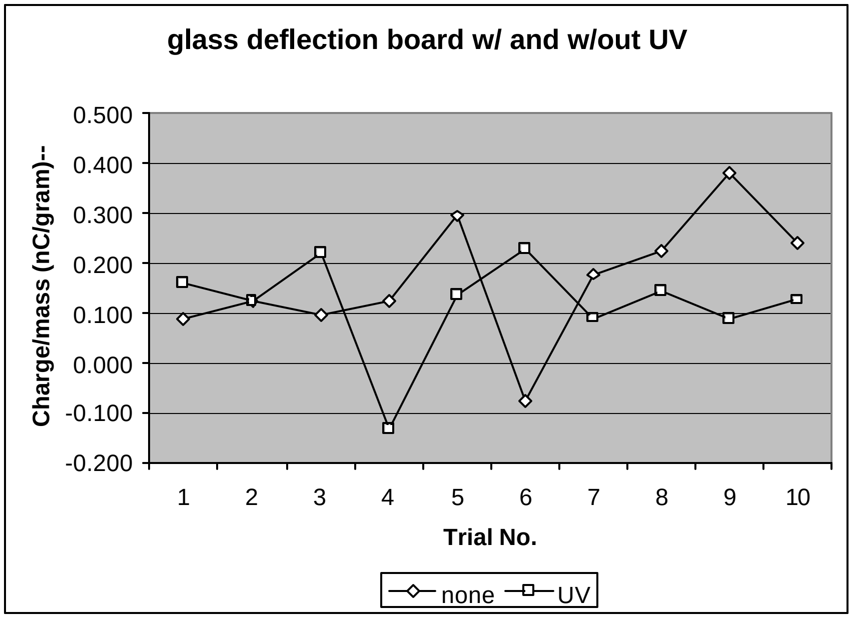

Figure 6. Simulant charge with glass deflection board with and without UV

The glass deflection trials showed that a net negative average charge of .167 nC/gram accumulated in the Faraday cup. It appears again that UV radiation does not affect the charging of the particles. The glass yielded the most positive of the tribo-charged values for all three materials.

5. Conclusions

We can compare the final average charge for each material tested on the deflection board to illustrate how the simulant reacts against glass, copper and acetate. Figure 7 below shows the average charge measured by the electrometer for each material. We are comparing all three cases without UV since UV had a negligible effect.

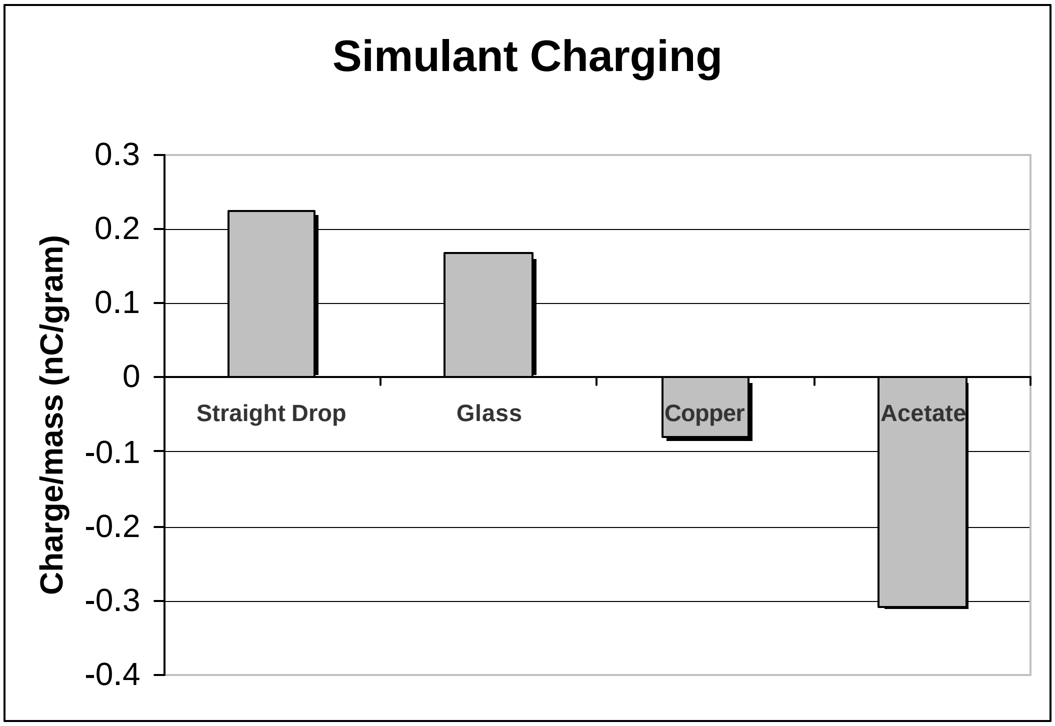

Figure 7 Comparison of the average charge on the simulant for the four basic trials.

Looking at the relative charges accumulated in figure 7, the straight drop experiment produced the most positive charge. The glass surface caused positive charges to be deposited on the simulant, while the copper and acetate surfaces produced negative charges. Obviously, of the three materials tested, copper contributes least to the charging of the simulant and the acetate contributes most.

We speculate that in the straight drop trials that one or both of two factors have contributed to the net positive charge in the cup. First, although the simulant is "grounded" before placing into the sample holder, the holder itself could induce a net positive charge as the particles are falling out. Secondly, the smaller particles in the free fall over a distance of 29 cm may, through thin air resistance, have drifted off the vertical and missed the cup. If the smaller particles tended to carry a negative charge [11] then the larger particles in the cup will carry a positive charge. In future experiments, we anticipate using an AC corona to neutralize the sample after leaving the holder.

The charge measured from the three deflection board surfaces does not fit "nicely" into the traditional triboelectric series table. Many factors could have also influenced this outcome. The simulant is not a homogeneous material, it is composed of ten different oxides. Nor is the simulant of one grain size. Therefore, different particles of differing compound percentages and weights will react differently to each deflection board surface.

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6. References

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